M51 revisited: a genetic algorithm approach of its interaction history

Christian Theis* and Christian Spinneker
Institut f. Theoretische Physik und Astrophysik, Universität Kiel, 24098 Kiel, Germany

Abstract.
Detailed models of observed interacting galaxies suffer from the extended parameter space. Here, we present results from our code MINGA which couples an evolutionary optimization strategy (a genetic algorithm) with a fast N-body method. MINGA allows for an automatic search of the optimal region(s) in parameter space within a few hours to a few days of CPU time on a modern PC by investigating of the order of 10^5 models. We demonstrate its applicability by modelling the HI intensity and velocity maps of the interacting system M51 and NGC 5195. We get a good fit for the HI intensity map and we can reproduce the counter-rotation feature of the HI arm. Our result corroborates the results of Salo & Laurikainen (2000) who favour a model with multiple passages through M51's disk.

Keywords: galaxy interaction, galaxy evolution, numerical modelling, M51

1. Introduction

Interacting galaxies are a rich source for studying many different astrophysical phenomena. The perturbation exerted by a companion can result in a strong tidal response like a bridge or tidal tails. On smaller scales the perturbed interstellar medium might react with induced star formation, maybe even with a star burst or the formation of a tidal dwarf galaxy. On larger scales, the appearance of a galaxy might change substantially, e.g. when spiral galaxies are transformed into ellipticals. Additionally, the evolution of tidal tails is rather sensitive to the galactic mass distribution, especially to the dark matter profile in the outer regions. Thus, detailed models of interacting galaxies give not only their dynamical interaction history, but they provide us with constraints on star formation timescales or they allow for measurements of the mass distribution in galaxies.

The main difficulties for modelling interacting galaxies are the large parameter space and the substantial CPU-time of a single self-consistent simulation. Though there has been a tremendous increase in computational power, we are still completely unable to cover the whole parameter space by self-consistent N-body simulations. E.g. covering a

* theis@astrophysik.uni-kiel.de

7-dimensional parameter space by 5 values per dimension and assuming 3 CPU-h per simulation results in about 27 CPU-years. Thus, a first step in detailed modelling must be an efficient search in parameter space for interesting regions followed by detailed investigations of these regions. Genetic algorithms combined with the fast, but approximative restricted N-body method have proven to be a good tool for such an investigation (Wahde, 1998; Theis, 1999). Here, we present first results of our modelling of M51. We derived our results directly from high resolution HI intensity and velocity maps by this proving that our code MINGA allows not only for uniqueness checks of preferred model scenarios, but also for an automatic fit of high-resolution observations.

The M51 encounter in a nutshell

M51 is a prototype interacting galaxy which has been modelled many times. E.g. Toomre & Toomre (1972) presented a model derived from restricted N-body simulations giving a good representation of the optical image. Their best model corresponds to an elliptic (but close to parabolic) orbit with a perigalactic passage 10^8 years ago at a distance of 15 kpc[1]. They assumed a mass ratio of 1:3 between NGC 5195 and M51. Based on similar initial conditions, Hernquist (1990) performed self-consistent simulations using a TREE-code. In addition to the previous models, the self-gravity allowed for the emergence of a central spiral structure whereas the results in the outer regions are rather similar to the results of the restricted N-body calculations.

The picture became more complicated when HI observations were available: Rots et al. (1990) found an extended, lopsided HI tail with a mass of $\sim 5 \cdot 10^8 \mathcal{M}_\odot$. This tail cannot be explained by the earlier models based on optical data. It has a projected length of about 80 kpc and a width of 9 kpc. Parts of the HI arm are in counter-rotation with respect to regions north of the center of M51. Additionally, a high-speed gas lump was found close to the position of NGC 5195. Several small but regularly organized HI clumps have been detected north of NGC 5195. Recently, Salo & Laurikainen (2000) found two regions in parameter space which give a good match to the intensity maps. Both of them are characterized by elliptic orbits with similar galactocentric passages. However, they differ by the orientation of their angular momentum and the number of recent passages through the disk of M51. Taking the velocity data into account their models seem to favour multiple disk passages. In another set of models – also using a genetic algorithm – Wahde & Donner (2001) reproduced the HI maps with a hyperbolic encounter, but they failed for the kinematics.

[1] scaled to a distance of 8.4 Mpc to M51.

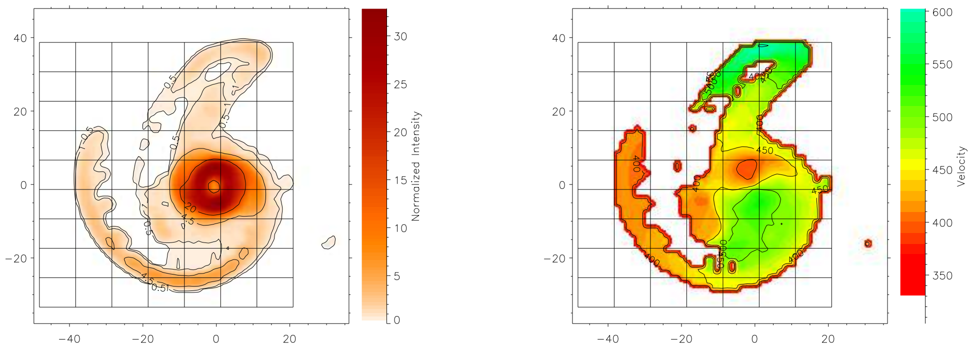

Figure 1. Intensity and velocity map derived from the MINGA fit.

2. The MINGA modelling

Optimization schemes based on a genetic algorithm (GA) mimic natural evolution assuming that the "population" improves its adaptation to the "environmental" constraints during the course of evolution. Details of the implementation of that concept for modelling interacting galaxies, especially with respect to our code MINGA can be found e.g. in Theis & Kohle (2001). Additionally, we implemented a couple of new features in MINGA like masking and emphasizing parts of the reference images, a direct usage of observational maps (FITS images) including both intensity and velocity maps, a consistent treatment of dark halo potentials for the orbit determinations, different reference map geometries and an extended set of fitness evaluation functions.

In a first series of MINGA runs we constrained the interaction by using *only* the HI intensity map. Though we got quickly a nice fit, the best models were unphysical, because the companion's final position was in front of M51 clearly violating optical observations. In a second series of GA runs we included also the HI velocity map for the evaluation of the fitness function by calculating a weighted mean of the matches to both, the intensity and the velocity map. Additionally, we increased the size of the population to 500 and followed the evolution for 500 generations. By this, we found solutions qualitatively similar to the observations (Fig. 1): the HI intensity map is very nicely reproduced, including the HI clumps north of NGC 5195. Additionally, the counter-rotation is recovered. The only feature which is still missing in all reasonable models is the high velocity lump north of M51. The parameters for our best model give a mass ratio between NGC 5195 and M51 of about 0.3, a highly elliptic orbit and a pericentric distance of about 12 kpc. The evolution since the last perigalacticon is shown in Fig. 2.

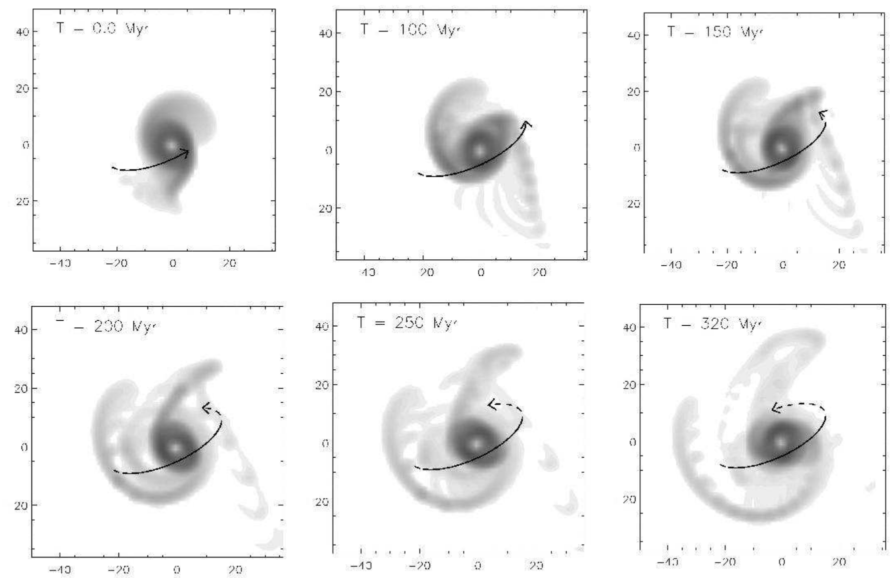

Figure 2. Temporal evolution of the HI distribution in the M51 system since the last perigalactic passage. Shown is the projection onto the plane of sky.

3. Summary

By combining intensity and velocity maps our genetic algorithm code MINGA was able to perform an automatic fit for modelling the interaction between M51 and NGC 5195. Our best model corresponds to a highly elliptic orbit with two recent passages of NGC 5195 through the disk of M51. Thus, our calculations corroborate the results of Salo & Laurikainen (2000).

Acknowledgements. We are grateful to L. Athanassoula and A. Bosma for providing the HI data on M51 and to P. Charbonneau and B. Knapp for making their program PIKAIA available.

References

Hernquist, L. 1990, in *Dynamics and Interactions of Galaxies*, R. Wielen (ed.), p. 108

Rots, A.H., Bosma, A., van der Hulst, et al. 1990, AJ, 100, 387

Salo, H., Laurikainen, E. 2000, MNRAS, 319, 377

Theis, Ch. 1999, Rev. Mod. Ast., 12, 309

Theis, Ch, Kohle, S. 2001, A&A, 370, 365

Toomre, A., Toomre, J. 1972, ApJ, 178, 623

Wahde, M. 1998, A&A Suppl. Ser., 132, 417

Wahde, M., Donner, K. 2001, A&A, 379, 115